Competency 1.8 **Radiation protection personnel shall demonstrate a working level knowledge of the application of engineered radiological controls and facility design, including containment/confinement systems.**

1. SUPPORTING KNOWLEDGE AND/OR SKILLS

a. Discuss the general principles relating to the design and installation of radiation protection containment/confinement systems including the following radiological protection considerations:
   - Layout design for nuclear facilities
   - Design and selection of components for nuclear facilities
   - Selection of materials and the associated surfaces for components used in radiological control areas
   - Design, construction, and operation of containment/confinement systems to minimize internal radiation exposure including:
     - Engineered ventilation
     - Engineered containment
     - Hot cells
     - Radioactive liquid and solid waste processing facilities
   - Design, construction, and operation of systems that minimize personnel external radiation exposure including:
     - Shielding
     - Interlock systems

b. Discuss the design and application of temporary engineered radiological controls.

2. SUMMARY

Containment/Confinement Systems
DOE Order 6430.1A, *General Design Requirements* provides general design criteria for use in the planning, designing, or acquiring of a facility for DOE. When considering the radiological concerns associated with the design, construction, and operation of containment and confinement systems, the Order (p. 13-9) states, "special facilities shall be designed to minimize personnel exposures to external and internal radiological hazards, provide adequate radiation monitoring and alarm systems, and provide adequate space for health physics activities. Primary radiation protection shall be provided by the use of engineered controls (e.g., confinement, ventilation, remote handling, equipment layout, and shielding); secondary radiation protection shall be provided by administrative control. As Low As Reasonably Achievable (ALARA) concepts shall be applied to minimize exposures where cost-effective."

<u>Nuclear Facility Layout</u>

Nuclear facilities must be arranged to facilitate operation, maintenance, inspections, radiation, and radiological control. The public, workers, and the environment are protected by designing facilities to:

- Isolate radioactive from nonradioactive areas.
- Provide shielding to protect workers from direct radiation.
- Control and minimize radioactive effluents to the environment.
- Limit access to hazardous areas.
- Control and minimize the release of radioactivity from systems designed to contain radioactive materials.
- Facilitate area and component decontamination.

<u>Component Design for Nuclear Facilities</u>

When designing and selecting components for a nuclear facility, care must be taken to include an evaluation of the radiological conditions to which the component may be subjected or under which the component will operate. For example, electronic components for use near a reactor must be capable of operating properly in the presence of potentially high gamma or neutron fluence rates. Not only must equipment be designed to withstand external radiological conditions, components must be capable of containing the radioactive material they are designed to process or transport. If high dose rates from penetrating radiation are expected, components must be adequately shielded. Shielding must provide adequate attenuation and minimize radiation streaming and "hot spots" associated with joints and corners in shielding material.

Pipes and ducts should not have stagnation areas where deposition of radioactive material may occur. The use of any component or system that has corners, crevices, etc., where deposition could occur, should be avoided when possible. For components used in the handling or storage of fissile materials, component geometry and the use of neutron absorbers should be considered for criticality prevention.

For ease of decontamination, equipment should be readily accessible and easy to disassemble (as is necessary for maintenance). During the design or selection process, contact or remote maintenance must be considered. Contact maintenance is less expensive, but may result in higher personnel exposures. Remote maintenance is expensive and typically must be included in initial facility design.

Radiological Area Materials (RAM)

Materials and material finishes must be relatively smooth and nonporous. Wood and other porous construction materials should be avoided for areas likely to become contaminated. Concrete is highly porous and very difficult to decontaminate unless a nonporous finish is applied. For a given choice of surface material, the ease of decontamination will be related to the manner in which the surface is contaminated and the particular decontaminating chemical agent chosen. Contamination tends to become incorporated in metallic surfaces, making removal difficult. Organic surfaces (paints, plastics, and textiles) and vitreous surfaces (glass, porcelain) have a capacity for ion exchange that is probably the most important contamination mechanism. The use of strippable paint is recommended for areas and components requiring frequent decontamination.

In order to provide ease of decontamination, an ideal surface should have these features:

- Be nonabsorbent, since porous materials are very difficult to decontaminate
- Contain as few acidic groups as possible, since these groups are chemically reactive
- Have a low moisture content
- Be protected from exposure to solvents or chemicals, which attack the material
- Possess sufficient chemical resistance to withstand decontaminating agents
- Be capable of withstanding abrasive action
- Be smooth with no cracks and ledges

Since no one material exhibits all these features, compromises have to be made with respect to use of materials which have deficiencies with respect to decontamination. As mentioned above, the permanent surface will often be covered by a temporary surface which can be easily removed for decontamination purposes. Among the more frequently used strippable coatings are latex paint, polyvinyl chloride (PVC) or polyvinyl acetate (PVA) sheet, coated paper, or polyethylene.

Piping, valves, pumps, and other components in nuclear facility systems should contribute as little as possible to radioactive source terms. Consideration must be given to the corrosiveness of materials that may contact component surfaces and the radiological effect of corrosion layer buildup and transport throughout facility systems. For example, the use of stellite valve seats in reactor systems has been largely discontinued due to the high concentration of cobalt in stellite. Valve seat wear and corrosion results in the transport of higher than normal levels of cobalt to the reactor, where the cobalt may be activated and transported throughout the reactor coolant system. Materials for use near operating reactors must also be selected to minimize activation as a result of neutron exposure.

Materials likely to be subjected to intense radiation fields must be selected such that structural stability is maintained. Materials should not decompose or deteriorate under expected radiological conditions.

Design, Construction, and Operation for Internal Doses ALARA

The safety-design philosophy for hazardous radionuclides has evolved into the central theme "containment and confinement." That is, contain the material, or process, to ensure a barrier exists between the worker and the toxic substance. If the barrier breaks down, concentrate, or confine, the released material to a limited area. This philosophy implies the need for multiple barriers. The containment protects the worker from the hazards of the material. A source enclosed in a capsule would be a simple means of containing or enclosing the material. Sometimes both the substance and the process need to be contained so containment/confinement systems, such as gloveboxes, hot cells, and other structures are used.

Confinement systems in which radioactive material is handled, or processed, must be designed and operated to maintain personnel exposures ALARA under normal and abnormal operating conditions. This includes minimizing exposure, not only to surface and airborne contaminants, but also to penetrating radiation. Both occupational exposure and exposure of members of the public must be considered when designing such systems.

The special features of plutonium and certain other radionuclides require that these substances be handled most carefully. Figure 1, following, depicts a typical plutonium laboratory confinement system. This need for safety arises from four main features of the materials:

1. They are unstable substances, whose decay results in the release of radiation. This radiation may present a hazard, even if one is distant from the source.
2. These elements are toxic. Intake into the body may result in long term deposition in bone and other organs with severe local damage at these sites.
3. The substances are fissile. When enough of such material is present in the proper setting, a fission chain reaction can occur. Such an event would release large amounts of energy and radiation.

4. Some forms of these substances are pyrophoric (i.e., they ignite spontaneously). Once started, a fire could spread rapidly and result in great damage.

To reduce the hazard potential, and to achieve safety in handling these substances, control of these features is required.

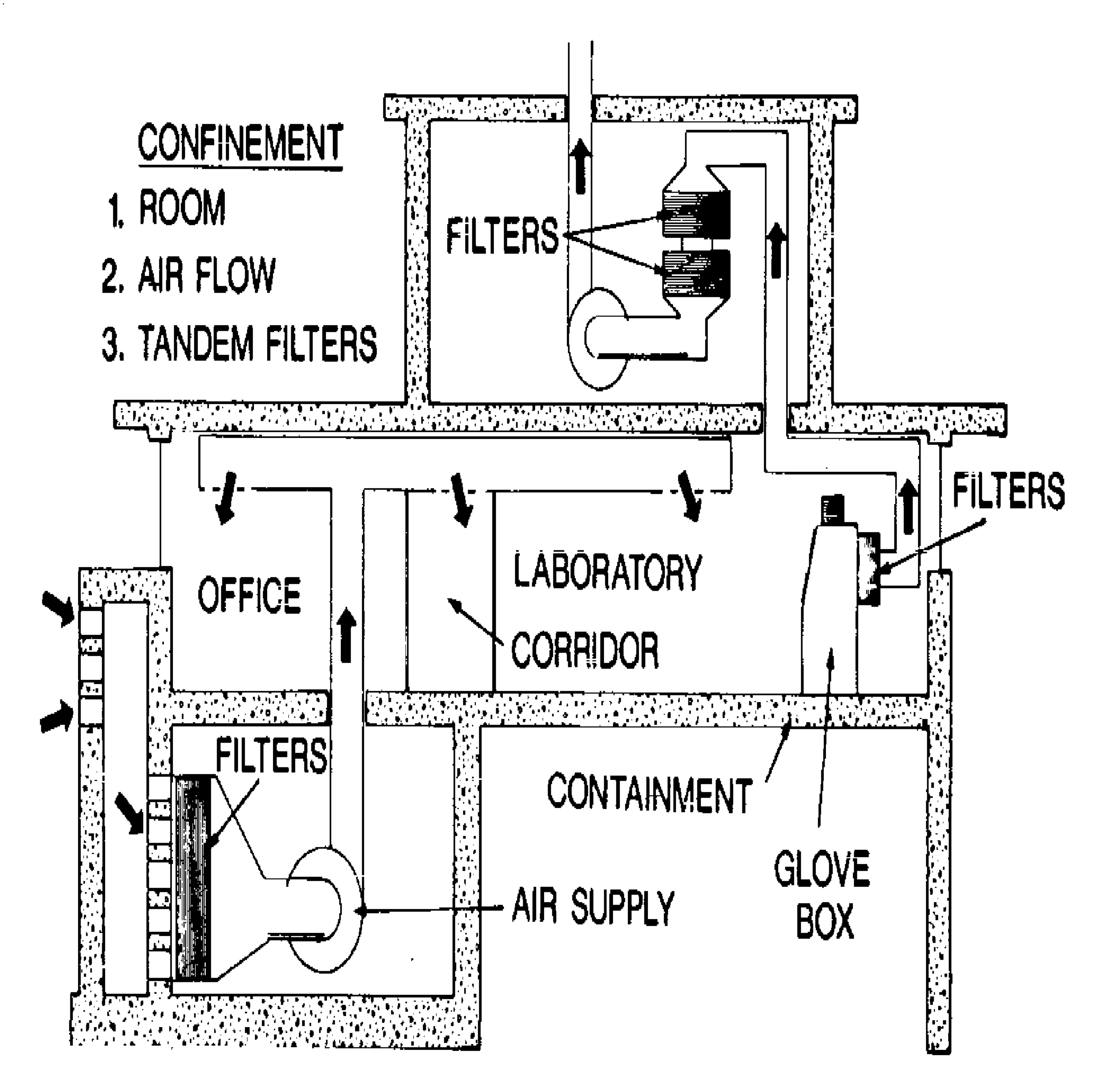

Figure 1
Confinement and Containment in a Plutonium Laboratory

The need for confinement systems is greatest when using large amounts of long half-life, highly-radiotoxic substances requiring frequent processing in operations exhibiting a high-release potential. For processes involving small amounts of short half-life, low-hazard radionuclides in infrequent processes of low release potential, the worker and material may be allowed in the same environment.

Engineered Ventilation (Confinement)

Effective, well-designed ventilation systems are commonly used to control occupational exposure to radiological hazards. There are two generic classifications of ventilation: 1) general exhaust systems and 2) local exhaust systems.

The general exhaust system is used for heat control and/or removal of contaminants generated in a space by flushing out a given space with large quantities of air. When used for contaminant control, enough outside air must be mixed with the contaminant so that the average concentration is reduced to a safe level. The contaminated air is then typically run through a filter or scrubber and discharged to the atmosphere. This type of exhaust system is normally used when local exhaust is impractical.

The local exhaust system operates on the principle of capturing a contaminant at, or near, its source. It is the preferred method of control because it is more effective and the smaller exhaust flow rate results in lower heating costs compared to high-flow rate general exhaust requirements.

For either exhaust system, it is important that the flow of air go from the area of least contamination to the area of greater contamination. In other words the system should create a pressure drop from the "clean area" (higher pressure) to the "dirty area" (lower pressure). This will prevent the migration of contaminants to the clean area. In order to achieve this result, a ventilation engineer should be consulted to design the optimal system for the contaminant(s). Since a major radiological concern is worker and public exposure to airborne contaminants, containments are generally designed to maintain internal negative pressure with respect to the surrounding atmosphere.

A confinement system generally involves an off-gas or ventilation system, typically composed of treatment devices (particulate filters, charcoal absorbers, scrubbers, etc.) to minimize gaseous and particulate contaminant concentrations, and the ductwork necessary to confine the gaseous stream prior to releasing it to the environment or other clean area. The ventilation system is generally referred to as the "confinement" system, since contaminants are not actually contained by the system but are simply confined within the system until discharged. Buildings, rooms, and other enclosures may also be considered part of a confinement system, if they function as a backup to the primary means of material containment.

Engineered Containment

The term "containment" generally refers to the principle enclosure (e.g., building, room, cubicle, glovebox, fume hood, conveyor tunnel, etc.) that isolates the radioactive material from the surrounding work space or environment.

DOE Order 6430.1A specifies the design criteria (reliability, redundancy, and loading) and operating, maintenance, and decommissioning requirements for major DOE construction. The Order is divided into chapters called divisions. Division 11, "Equipment," deals primarily with requirements for enclosures (containments) for hazardous materials, and includes subsections for general considerations, construction, fire protection, ventilation, and operational compatibility.

Hot Cells

In processes involving highly radioactive materials, such as irradiated plutonium samples that have not been separated from fission products, hot cells are used to provide shielding. Figure 2 depicts a typical hot cell design and layout, and figure 3, following, is an example of a remote handling device for a hot cell.

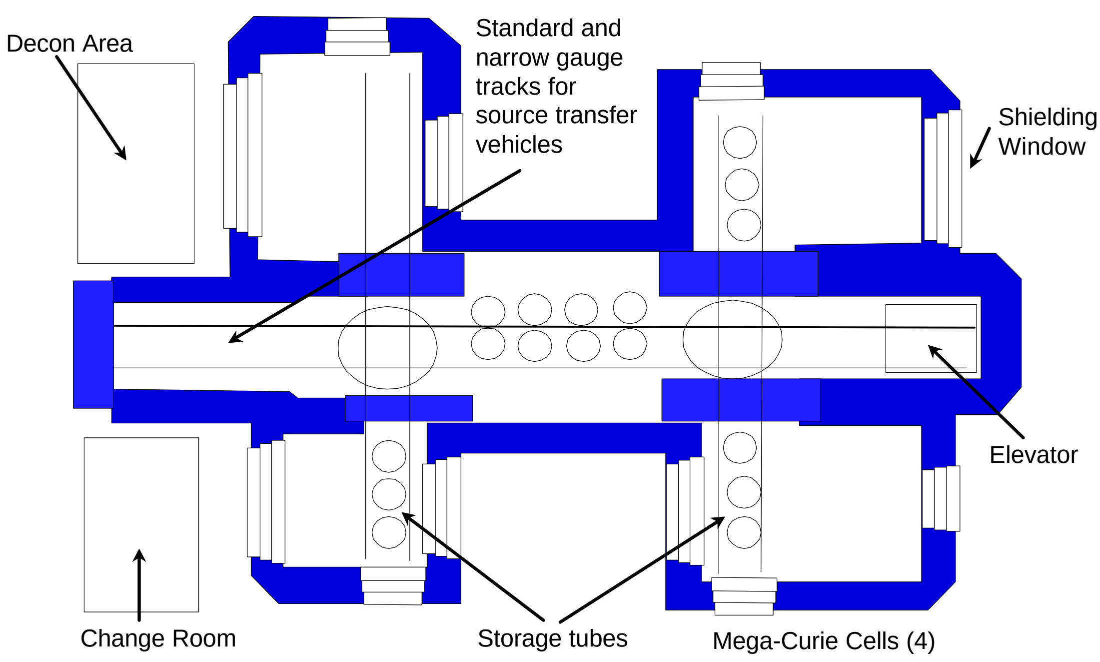

Figure 2, Hot Cell Facility

The probability of accidents such as spills, unexpected chemical reactions, small fires, or explosions should be considered. Safety design will attempt to overcome, or minimize, the effects of such incidents. However, since these events may still occur, it is extremely important that personnel be trained in methods of combating such episodes. Needless to say, plans must be formed that treat the problems arising out of such accidents.

Appropriate combinations of construction materials are used to provide protection from penetrating radiation (gamma and neutron). Hydrogenous materials, such as concrete and oil, are used to shield neutron radiation; while denser materials, such as lead and steel, are used to shield gamma photons. Viewing ports are constructed of leaded glass, oil-filled glass, or other substances to minimize dose rates.

Transfer of items into and out of the hot cell, and movement of items in the hot cell, must be done so as to preserve the barrier integrity. Barrier integrity can be preserved by using remote handling devices (robots) and remote controlled vehicles.

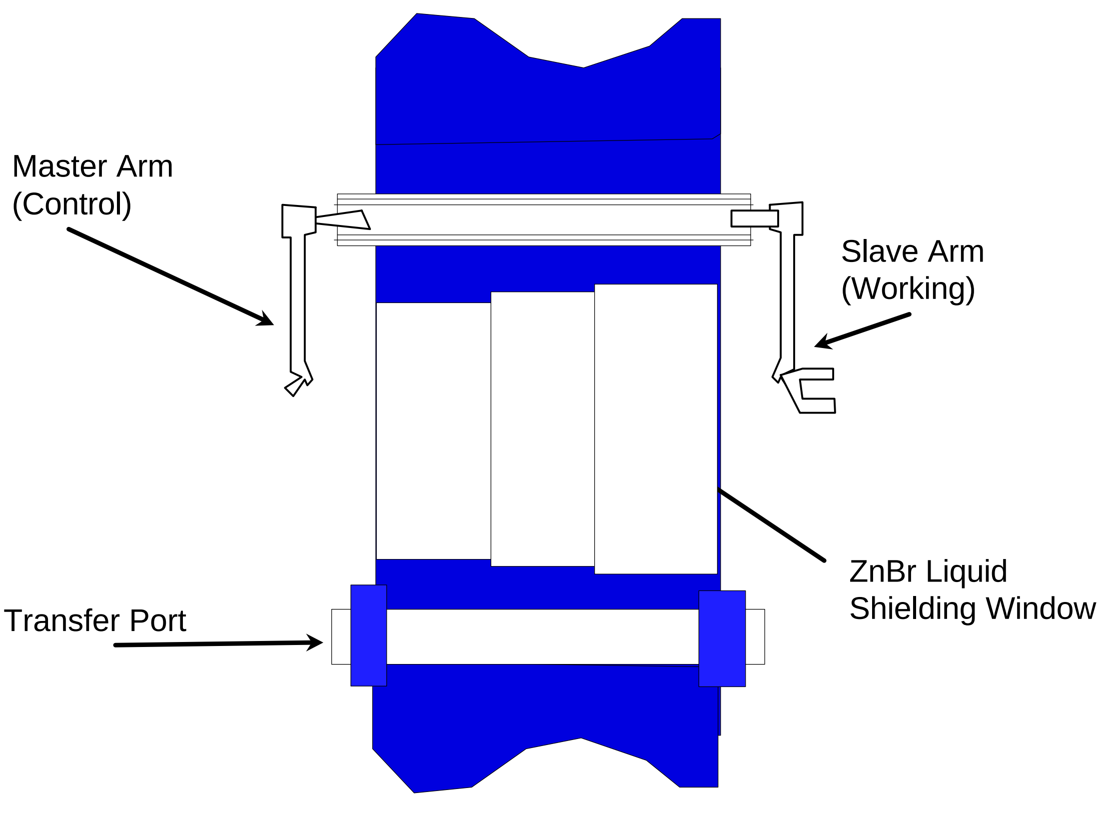

Figure 3, Remote Handling Device

Solid and Liquid Radwaste Facilities

Radioactive waste consists of solid, liquid, and gaseous materials from nuclear operations that are radioactive, or become radioactive, and for which there is no further use. Wastes are classified as high-level (spent nuclear fuel and fuel reprocessing byproducts having radioactivity concentrations of hundreds of thousands of curies per gallon or cubic foot) or low-level (all other wastes). Definitions of these radioactive wastes are:

- High-level waste

This is highly radioactive waste material that results from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid waste derived from the liquid that contains a combination of transuranic waste and fission products in concentrations requiring permanent isolation.

- Low-level waste

Waste that contains radioactivity and is not classified as high-level waste, transuranic waste, spent nuclear fuel, or byproduct material as defined in Section 11e(2) of the Atomic Energy Act, as amended, is low-level waste. Test specimens of fissionable material irradiated only for research and development and not for production of power or plutonium may be classified as low-level waste provided the concentration of transuranic activity is less than 100 nCi/g.

Facilities that process radioactive waste use containment systems such as pipes and encasement; vessels such as drums, tanks, capsules, bins, and B-25 container boxes. Before containing radioactive waste for processing, facilities should try to segregate it, as much as is practical, by type (sludge, salt, high activity, and low activity). This will make accessibility for future processing easier.

Double walled pipes, or pipes within a secondary confinement structure encasement, must be used in all areas where the primary pipe leaves the facility. In areas within the facility, the use of a double walled pipe should also be strongly considered. Leakage monitoring must be provided to detect leakage into the space between the primary pipe and the secondary confinement barrier. Early detection of leaks is important to mitigate events that could lead to a radioactive release to the environment.

Storage tanks should be double hulled with a monitor placed between the hulls for early detection of leaks. There should also be detection devices inside any secondary containment system for early detection of leaks to help mitigate events that could lead to a radioactive release. Storage vessels that are not vented can result in pressure buildup, leading to rupture and spillage; therefore, care must be taken when opening them (the design and use of some type of restraining device is strongly urged before opening vessels that contain hazardous or radioactive waste). Leaking waste storage systems must not be used to receive waste unless secondary containment can be maintained and temporary operations can be performed without releasing radioactive liquid to the environment. This must be backed up with the support of formal documentation such as safety analysis reports (SARs), operational safety requirements (OSRs), operation standards, etc. High-level waste must be stored at pressures lower than those of ancillary systems.

Any secondary containment system must be capable of containing liquids that leak into it from the primary system, and must be equipped with transfer capability to retrieve the leaked liquid. Secondary containment systems for solidified high-level waste must provide physical isolation of the waste from the environment. Other engineering controls include devices to provide liquid volume inventory data and to prevent spills, leaks, and overflows from containment systems. Some examples of such controls include level-sensing devices, liquid level alarms, and maintenance of sufficient freeboard.

Monitoring and leak detection capability is incorporated in the engineering system to provide rapid identification of failed containment and measurement of abnormal temperatures. The following, at a minimum, should be monitored:

- Temperature
- Pressure
- Radioactivity in ventilation exhaust
- Liquid effluent streams associated with high-level waste facilities
  In addition, facilities storing liquid high-level waste should also monitor:
- Liquid levels
- Sludge volume
- Tank chemistry
- Condensate and cooling water

A system of ground water or vadose zone monitoring wells that meet the Resource Conservation and Recovery Act (RCRA) requirements per 40 CFR 264, *Students for owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities* must be installed, as a minimum, around clusters of liquid waste storage tanks.

Facilities that use cathodic corrosion protection systems must include engineered features that protect against abnormal conditions such as stray currents or system failure. Calibrate the cathodic protection system annually, and inspect and/or test all sources of impressed current at least every other month.

Even though safeguards, such as secondary containment systems and leak detection monitors, are in place at waste processing facilities, contingency plans to control radioactive release must also be developed in case the engineered controls fail. For example, if a release results from a spill and the integrity of the system is not damaged, the system may be returned to service as soon as the condition has been corrected. For emergency situations involving liquid high-level waste, spare capacity with adequate heat dissipation capability must be maintained to receive the largest volume of liquid contained in any one tank. To achieve this, maintain adequate transfer pipelines in operations condition. Interconnected tank farms with adequate transfer capabilities and spare capacity may also be considered as a single tank farm for purposes of the requirement found in DOE Order 5820.2A, *Radioactive Waste Management*.

Ventilation and filtration systems must be provided to maintain radionuclide releases within the guidelines specified in applicable DOE Orders. Ventilation systems shall be provided where the possibility exists for generating flammable and explosive mixtures of gases such as hydrogen/air or organics/air.

Design, Construction, and Operation for External Doses ALARA

Shielding

Obtain information on shielding types and thicknesses from a radiological specialist (e.g., a radiological engineer, ALARA specialist, or health physicist, as appropriate for the project). Consider temporary shielding when shielding would be needed only briefly or infrequently. Allow for space, support, and transport requirements. Consider special shielding, such as shield doors, leaded glass windows, covers for hot spots, transport casks, and shielded carts or forklifts.

The shielding design basis must be to limit the maximum exposure to an individual worker to one-fifth the annual occupational external exposure limits specified in current regulations and DOE Orders. Within this design basis, personnel exposures must be maintained ALARA. Specifically, the shielding must be designed with the objective of limiting the total effective dose equivalent (EDE) to less than one rem per year to workers, based on their predicted exposure time in the normally occupied area. The EDE must be the sum of all contributing external penetrating radiation (gamma and neutron). In addition, appropriate shielding must be installed, if necessary, to minimize nonpenetrating external radiation exposures to the skin and lens of the eye of the worker. In most cases, the confinement barrier or process equipment provides this shielding. Shielding and other radiation protection measures must be provided for areas requiring intermittent access, such as for preventive maintenance, component changes, adjustment of systems and equipment, etc. The projected dose rates, based on occupancy, time, and frequency of exposure, must not exceed one rem/year. Straight line penetration of shield walls must be avoided to prevent radiation streaming.

Remote shielded operation (i.e., with remote handling equipment such as remote manipulators) must be considered where it is anticipated that exposures to hands and forearms would otherwise approach the current extremity dose limit or where contaminated puncture wounds could occur.

Interlock Systems

Design

Emergency-off (SCRAM) buttons should be clearly visible, labeled, and readily accessible. Run/safe switches may be used to prevent startup of an accelerator or radiation source when a radiation area is occupied. Emergency exit mechanisms must be provided at all doors and manways. Emergency entry features are not precluded. Warning lights or annunciator signs should be located outside entrances to accelerator enclosures. Audible warning should be given inside accelerator enclosures before the accelerator is turned on. Search of a radiation area should be initiated by activating a "search start" switch. "Search confirmation" switches should also be provided. The interlock system should prevent beams from being turned on until after the search has been completed and acknowledged and the audible and visual warning light cycle has ended. Any violation of the area should cause the interlock system to immediately render the area safe. Restarting the accelerator should not be possible until the area has again been searched. A "controlled entry" mode may be desirable for some larger accelerators. Control device requirements for high-and very high-radiation areas can be found in Subpart F of 10 CFR 835.

Construction

The objective of a safety interlock system is to prevent injury or damage from radiation. To achieve this end, the interlock must operate with a high degree of reliability. Components and materials should be of high grade for dependability and long life. Materials that resist radiation should be selected for those components located in areas where the radiation levels are high enough to cause radiation damage.

Fail-safe circuits and components should be used whenever practicable. Fail-safe design takes into consideration the failure of primary alternating current (AC) power to the area, direct current (DC) power to logic circuits or beam-line components, or of the pressurized air that feeds air-actuated solenoids in safety devices. In each case, the safety interlock system should react to render the area safe in the event that a key safety component fails or the power source is lost.

Duplicate (parallel) circuits or redundant components should always be used in critical applications where the single failure of a circuit or device could lead to a hazard. In design of redundant circuits, parallel chains should be used. The chains should remain independent, and not neck down to a single connection or components. Independence should be carried all the way from duplicate sensors through to the devices or mechanisms that shut off the radiation source. Wherever possible, at least two different methods should be in place to remove the beam or radiation source. Examples of mechanisms appropriate to many accelerators are: removing high voltage to the radiation source, inserting beam stoppers, and turning off a magnet bend string.

To reduce the likelihood of accidental damage or deliberate tampering, all cables should be protected. Preferred methods are to use armor-covered cable or to run the cable in conduit. It is acceptable to lay cable in metal trays, particularly where long runs are involved, providing that the cable is run in conduit between the tray and the junction box or cabinet. When using conduit, or armored cable, the covering should be continuous with solid elbows and no inspection plates. For installations in high-radiation areas, particular attention should be given to selecting radiation-resistant cable.

Operation

Interlocks should be tested periodically, according to written procedures, and the results of the tests carefully recorded. Two types of testing are appropriate. Detailed, rigorous testing of the entire system should be done at the start of each running cycle. If the machine is operating continuously, a detailed test should take place at least every six months. These tests should demonstrate correct operation of all devices at entrances, all emergency-off switches, the interlock logic itself, and all redundant paths to the shutdown mechanisms.

In addition to the rigorous testing, overall operation of the system should be tested more frequently--once a week, to once a month, may be appropriate. Tests might typically involve violating security at a different entrance point each time and checking that the beam is shut off.

Temporary ALARA Engineering Controls

<u>Design</u>

Temporary controls, such as temporary shielding or portable ventilation devices, are typically a response to unanticipated problems. They may be removed when the problem is corrected.

Unlike temporary controls, permanent controls, such as shield walls and permanent ventilation systems, are established with facility design and startup to ensure that worker safety and regulatory compliance are a part of the radiological design basis of the facility. Permanent controls typically cannot be changed unless the regulatory requirements that initially made them necessary are changed.

Temporary Shielding

The following is a checklist for reducing occupational radiation exposure and is found in Appendix 3A of the *Radiological Control Manual*.

- Design shielding to include stress considerations
- Control installation and removal by written procedure
- Inspect after installation
- Conduct periodic radiation surveys
- Prevent damage caused by heavy lead temporary shielding
- Balance radiation exposure received in installation against exposure saved by installation
- Shield travel routes
- Shield components with abnormally high radiation levels early in the maintenance period
- Shield position occupied by worker
- Perform directional surveys to improve design of shielding by locating source of radiation
- Use mock-ups to plan temporary shielding design and installation
- Consider use of water-filled shielding

<u>Application</u>

Temporary shielding is installed, used, and removed by procedures such as those found in 10 CFR 835, *Occupational Radiation Protection*. Before installing temporary shielding, the effects of the additional weight on systems and components must be evaluated and established to be within the design basis. It must also be periodically inspected and surveyed to verify its effectiveness and integrity, and radiation surveys must be performed during its alteration or removal. Visibly mark or label temporary shielding with the following or equivalent wording: "Temporary Shielding - Do Not Remove Without Permission from Radiological Control." The shielding must also be periodically evaluated to assess the need for its removal or replacement with permanent shielding. Site procedures may identify specific shielding applications, such as the shielding of low activity sources or samples, that fall outside the recommendations of DOE or other procedures.

3. SELF-STUDY/ACTIVITIES AND SOLUTIONS

Exercise 1

Your facility has decided to start a new program; however, funds for this project will not allow for the construction of a new building. Therefore, an existing building must be modified/altered to house this program. The project will need a wet chemistry lab where millicurie and microcurie quantities of carbon-14, cesium-137, cobalt-60, gallium-68, iodine-131, and tritium will be used. There will also be classroom space, office space, a lunch room, and restrooms in this building. What are the radiological considerations that must be taken into account when revamping this building?

Exercise 2

A health physics graduate student has been given an assignment of designing a nuclear facility. What radiological considerations must the student take into account completing this assignment?

Exercise 1, Solution
(Any reasonable paraphrase of the following is acceptable.)

Remember that each facility will have its own unique set of concerns, so no list can be inclusive, but the following is a list of some important considerations for various aspects of building design that must be taken into account for this building.

The wet chemistry laboratory will need to be:

- Preferably located in a far corner of the building.
- A separate room, controlled so that only authorized personnel have access.
- Posted as a controlled area.
- Specially equipped with items such as:
  - Monitors and friskers
  - Exhaust fume hoods
  - Emergency showers
  - Eyewash stations
  - Spill control supplies
  - Portable survey instruments, e.g., calibrated G-M pancakes.
- Provided with proper air flow.
- Provided with proper contamination control measures by allowing room for:
  - Frisking
  - Stepoff pads
  - Used C-zone clothing bins.
- Provided with smooth, nonporous and nonreactive surfaces (for ease of decontamination).
- Supplied with generous provisions for anticipated decontamination: water, air, electricity, and other connections.
- Provided with standard lettered signs, indicators, readouts, etc., that are clearly legible from a reasonable distance away.

Exercise 2, Solution
(Any reasonable paraphrase of the following is acceptable.)

The basic ALARA philosophy can be described as limiting personnel and environmental radiation exposures to the lowest levels commensurate with sound economic and social considerations. However, the ALARA philosophy assumes that no radiation exposure should occur without a positive benefit, considering technological, economic, and societal factors. This statement implies that there is some risk, however small, with any exposure to radiation. One should always look for ways to reduce radiation exposure, as long as the cost of the consideration does not exceed the possible cost of the potential dose savings.

One of the best ways to achieve ALARA is by designing it into a facility from the very beginning. This ALARA engineering (or radiological engineering) ensures that radiation exposures are minimized when the facility goes into operation and that maintenance, repair, or modifications in the facility can be done safely and without significant contamination or radiation hazards.

Each facility will have its own unique set of concerns, so no list can be inclusive, but here is a list of are a few considerations for various aspects of building design that can serve as a starting point for an ALARA review.

- Reduce crud deposition
- Reduce airborne sources and gaseous leakage
- Use proper air flow
- Provide for proper contamination control measures
- Facilitate decontamination of:
  - Equipment
  - Personnel
- Radwaste
  - Equipment
  - Plugging
- Sampling
- Monitoring
- Instrumentation
- Access control
  - Traffic
  - Radiological areas
- Shielding
- Penetrations

- Routing of ducts, pipes, and cables or conduit (DPCs)
- Proper separation
- Proper segregation
- Proper placement of equipment
- Redundancy
- Accessibility
- Laydown and storage
- Equipment
  - Reliability
  - Qualification
- Human factors
  - Visual aids
  - Auditory factors
  - Human physical characteristics
  - Prevention of human error

4. SUGGESTED ADDITIONAL READINGS AND/OR COURSES

Readings

- 10 CFR 835, *Occupational Radiation Protection.*
- DOE N 441.1, *Radiological Protection for DOE Activities.*
- DOE/EH-0256T (Revision 1), *Radiological Control Manual*.

  NOTE: See Appendix 3A, Checklist for Reducing Occupational Radiation Exposure, pp. 3-35 & 3-36.
- DOE Order 5480.4, *Environmental Protection, Safety, and Health Protection Standards.*
- G-10 CFR 835, Revision 1, *Implementation Guides for Use with Title 10 Code of Federal Regulations 835*.
- International Commission on Radiological Protection. *Cost-Benefit Analysis in the Optimization of Radiation Protection (ICRP 37).* New York: Author.
- International Commission on Radiological Protection. *Recommendations on the International Commission of Radiological Protection (ICRP 60).* New York: Author.
- Pacific Northwest Laboratory. (1988). *Department of Energy Health Physics Manual of Good Practices for Reducing Radiation Exposure to Levels that are As Low As Reasonably Achievable (ALARA)* (PNL-6577). Richland, WA: Author.
- DOE Order 6430.1A, *General Design Requirements*.
- 40 CFR 264, *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.*
- DOE Order 5820.2A, *Radioactive Waste Management*, 9-26-88.
- DOE Order 5480.23, *Nuclear Safety Analysis Reports*.

Courses

- DOE/EH-0450 (Revision 0), *Radiological Assessors Training (for Auditors and Inspectors) - Fundamental Radiological Control,* sponsored by the Office of Defense Programs, DOE.
- *Applied Health Physics* - Oak Ridge Institute for Science and Education.
- *Health Physics for the Industrial Hygienist* - Oak Ridge Institute for Science and Education.
- *Safe Use of Radionuclides* - Oak Ridge Institute for Science and Education.
- *Radiation Protection Functional Area Qualification Standard* - GTS Duratek.